Modeling Long-Term Soil Organic Carbon Dynamics as Affected by Management and Water Erosion

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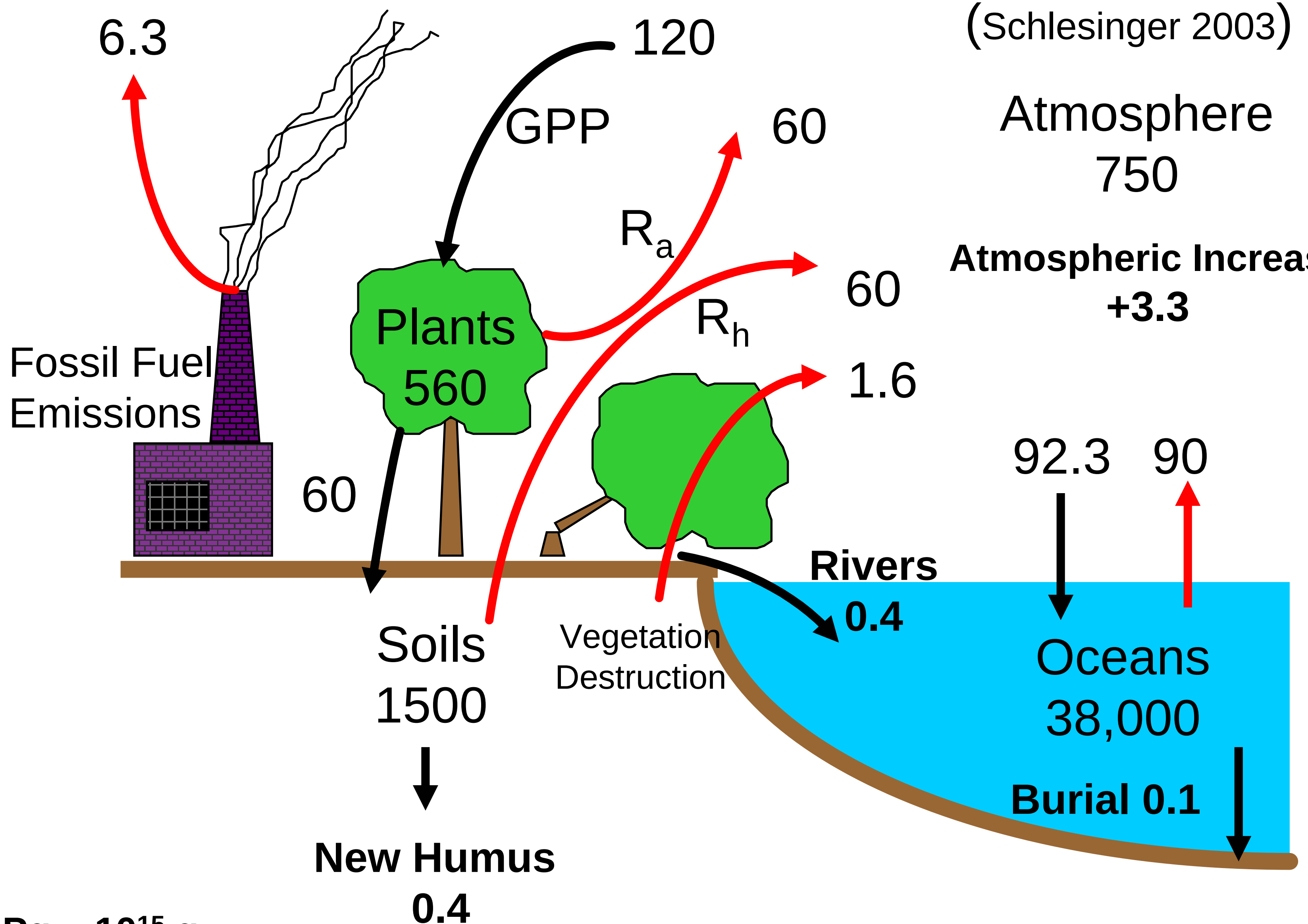
Objectives

- Review current hypotheses regarding the fate of eroded C from managed ecosystems
- Present modeling results of three long-term experiments documenting changes in soil C as affected by management and water erosion

Global Carbon Cycle (Pg C)

(Schlesinger 2003)



1 Pg = 10^{15} g
= 1 billion t

Average Global Carbon Budget ($Pg\ C\ y^{-1}$)

Annual C Fluxes	Mean	Uncertainty
	Source	
Fossil Fuel, Cement	**6.3**	**±0.4**
	Sinks	
Atmospheric Δ	**3.2**	**±0.1**
Net Oc.-Atm. Flux	**-1.7**	**±0.5**
Net Land-Atm. Flux	**-1.4**	**±0.7**
Land Use Change	**0.6 – 1.0**	
Residual Sink	**-1.3 – -3.1**	

Post et al. (2004)

Current Terrestrial Carbon Sinks ($Pg\ C\ y^{-1}$)

Terrestrial Carbon Sink	Rate ($Pg\ C\ y^{-1}$)
CO_2 Fertilization	0.9 – 3.1
Climate Change	-0.8 – +0.2
N deposition	0.1 – 2.5
Perennial Vegetation Regrowth	0.43
Fire Suppression	0.2
Erosion / Deposition (Stallard, 1998)	0.6 – 1.5
Long-lived Wood Products	0.3
Land Management	0.57

Post et al. (2004)

The fate of eroded soil and C: a landscape view

Date: 3/4/1972
Photographer: Eniz E. Rowland
Location: Whitman County, 6 miles East of Pullman, Washington
Watershed: South Palouse SWCD-25

USDA - Natural Resources Conservation Services

Soil transported by wind across fields

http://staff.terril.k12.ia.us/Mr.%20McGranahan/Agriculture/wind_erosion.htm

The fate of eroded soil and C: a global view

Rio de la Plata, the muddy estuary of the Paraná and Uruguay Rivers delivers huge amounts of DOC and POC to the Atlantic Ocean.

http://earth.jsc.nasa.gov/debrief/Iss008/topFiles/ISS008-E-5983.htm

Dust storm, Red Sea and Saudi Arabia

http://www.weru.ksu.edu/pics/nasa/

Two hypotheses

- **<u>Hypothesis 1:</u> Soil erosion leads to aggregate breakdown making physically-protected C accessible to oxidation (Lal, 1995)**
  - **1.14 Pg C y^{-1}**
- **<u>Hypothesis 2:</u> Buried C during erosion-sedimentation is replaced by newly fixed pedogenic C and may lead to a significant C sink (Stallard, 1998)**
  - **0.6 – 1.5 Pg C y^{-1}**

Global estimates of water erosion, CO_2 flux to atmosphere, and sediment transport to oceans (Lal, 1995)

- **Sediment transport to oceans:**
  - **19 Pg y^{-1}**
  - **0.57 Pg C y^{-1}**
- **Soil displacement by water erosion:**
  - **190 Pg y^{-1}**
  - **5.7 Pg C y^{-1}**
- **CO_2 flux from displaced sediments:**
  - **1.14 Pg C y^{-1}**

Linking terrestrial sedimentation to the C cycle

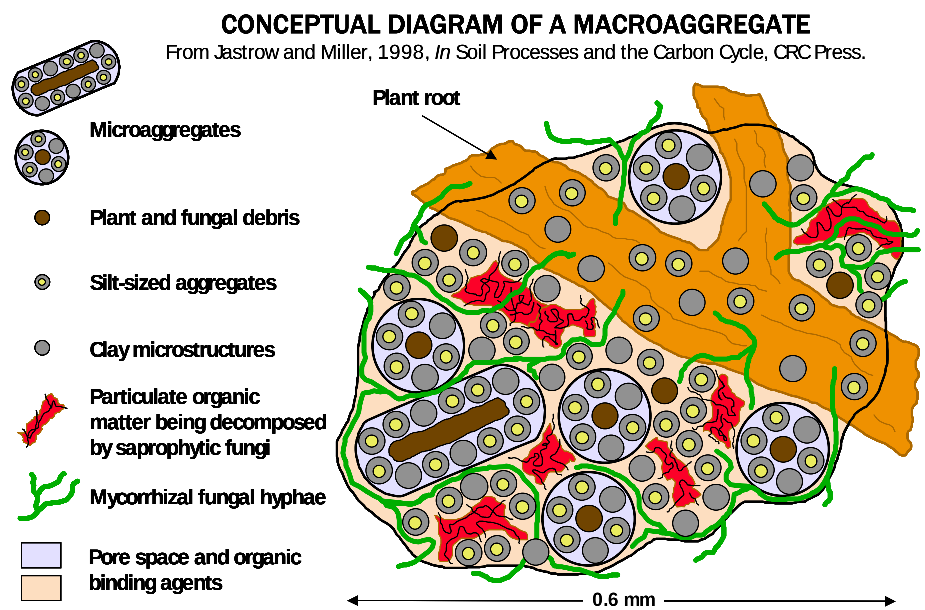
- **Stallard (1998) examined two hypotheses:**
  - **Accelerated erosion and modifications of hydrologic systems lead to additional C burial during deposition of sediments**
  - **Buried C is replaced by newly fixed C at sites of erosion or deposition**
- **Results of a latitudinal model across 864 scenarios (wetlands, alluviation + colluviation, eutrophication, soil C replacement, wetland NEP and CH_4) suggested a human-induced C sink of 0.6 – 1.5 Pg C y^{-1}**

Two types of uncertainties concerning the relationship between erosion-deposition processes and the C cycle

- **The first refers to the link between erosion / deposition and net primary productivity**
  - **At eroding sites, soil C removed by water, wind, or moved by tillage may be replaced by new photosynthetic C**
  - **At depositional sites eroded C may be buried and the site may increase even more its C content due to enhanced photosynthetic activity**

Two types of uncertainties concerning the relationship between erosion-deposition processes and the C cycle (cont'd)

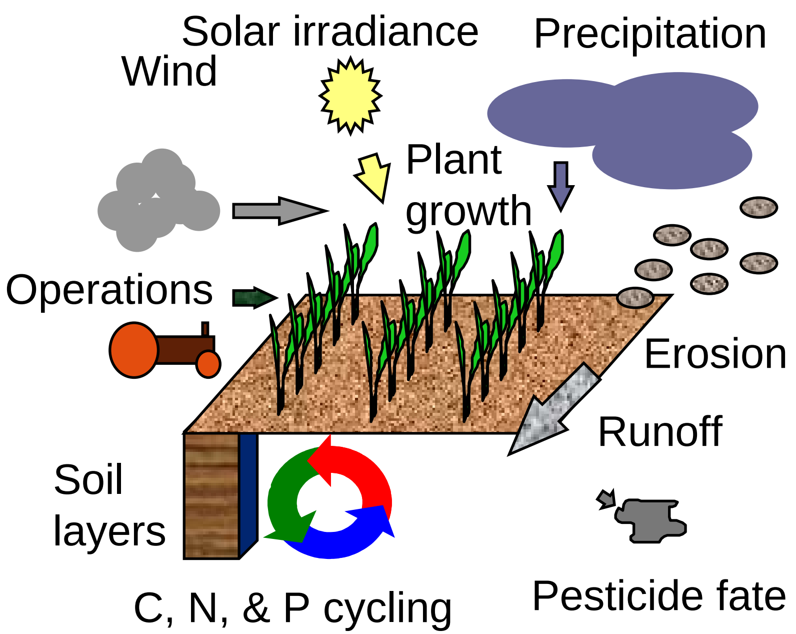
- The second concerns the fraction of the eroded or deposited C that evolves as CO_2
  - This fraction has been estimated as: 0.0 (Stallard, 1998; Smith et al., 2001), 0.2 (Lal, 1995, 2003), or even 1.0 (Schlesinger, 1995)
  - The hypothesis that eroded C essentially undergoes no oxidation when dislodged and transported to a new location needs to be tested



Jastrow and Miller (1998)

Integrating soil and biological processes at landscape scale through simulation modeling

EPIC Model



Representative EPIC modules

Williams (1995)

Izaurralde et al. (in review)

- **EPIC is a process-based model built to describe climate-soil-management interactions at point or small watershed scales**
  - **Crops, grasses, trees**
  - **Up to 100 plants**
  - **Up to 12 plant species together**
- **Key processes simulated**
  - **Weather**
  - **Plant growth**
    - **Light use efficiency, PAR**
    - **CO_2 fertilization effect**
    - **Plant stress**
  - **Erosion by wind and water**
  - **Hydrology**
  - **Soil temperature and heat flow**
  - **Carbon, Nitrogen, and Phosphorus cycling**
  - **Tillage**
  - **Plant environment control: fertilizers, irrigation, pesticides**
  - **Pesticide fate**
  - **Economics**

Simulating soil C erosion at the North Appalachian Experimental Station at Coshocton, OH

- Entire watershed divided into small bermed sub-catchments with separate treatments
- Treatments start in 1939; modified in the 1970s

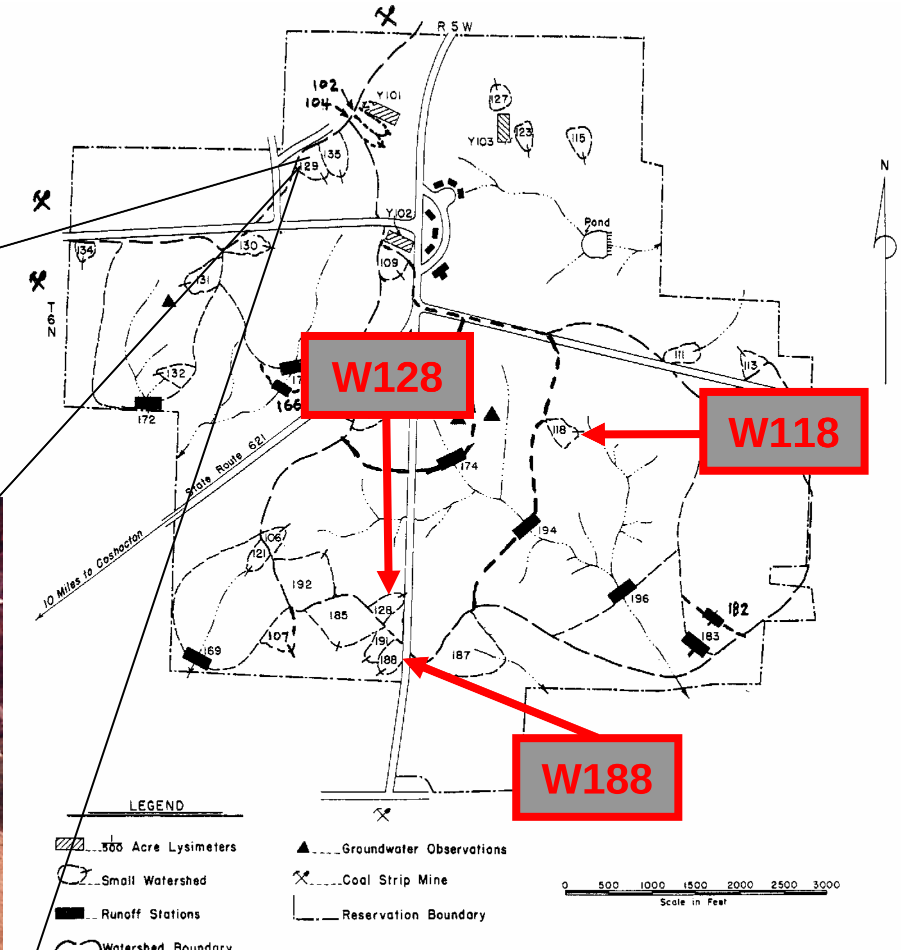


FIGURE 4.—North Appalachian Experimental Watershed, 1,047 acres of government-controlled land.

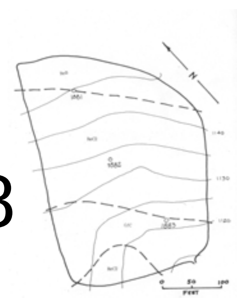
Land-use history for watersheds W128, W188, and W118

W128

W128

CWMM	NT corn	meadow	CT corn
1966	1975	1979	1984 – 2001

W188

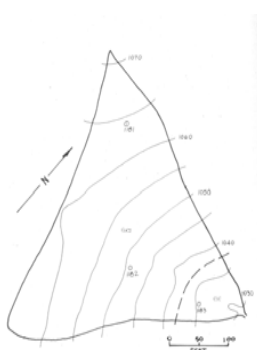


W188

CWMM	NT corn
1966	1971 – 2001

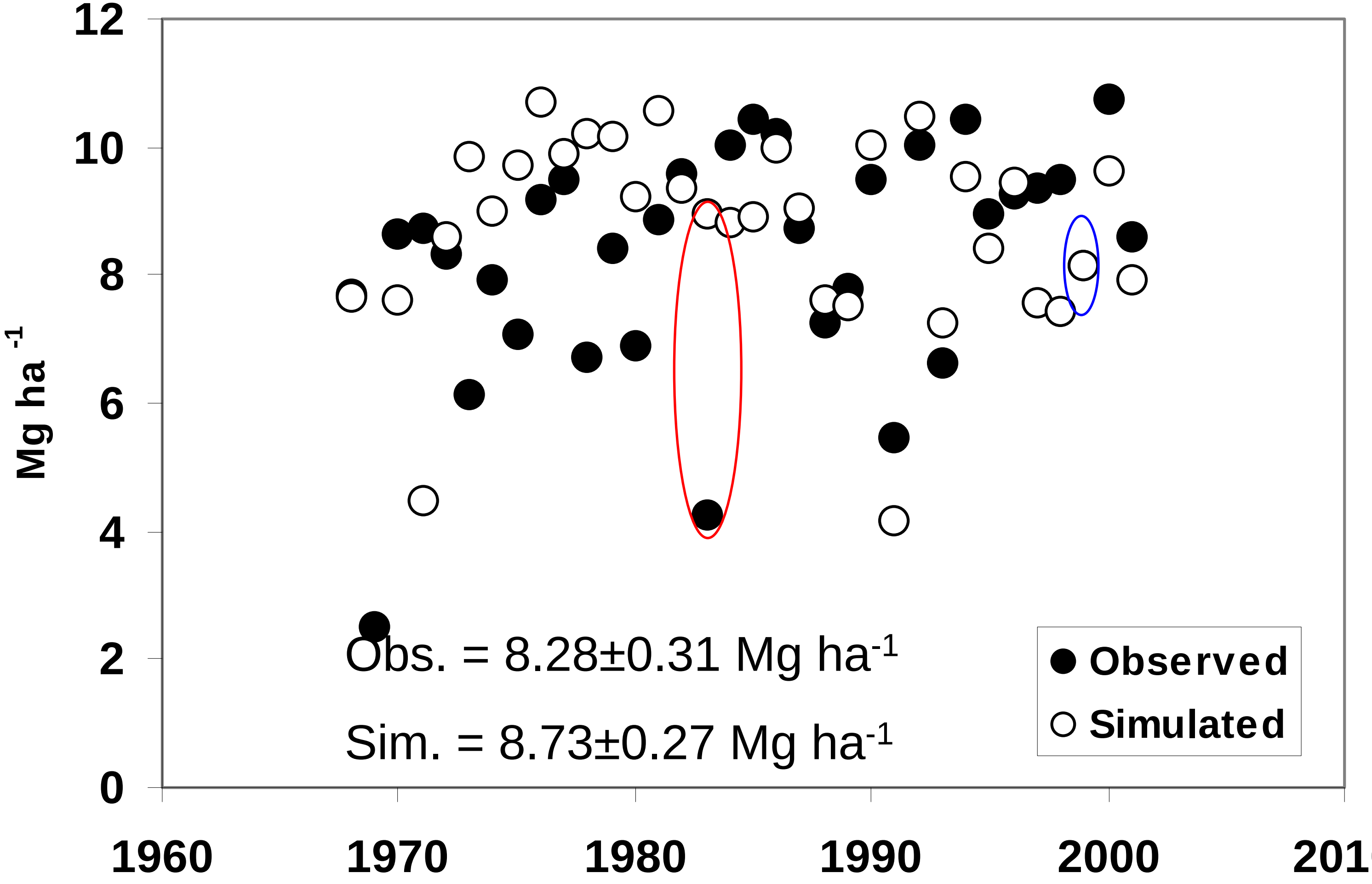
W118

corn-wheat-meadow-meadow (CWMM)	CT corn	meadow	NT corn-soybean
1951	1971	1976	1984 – 1999



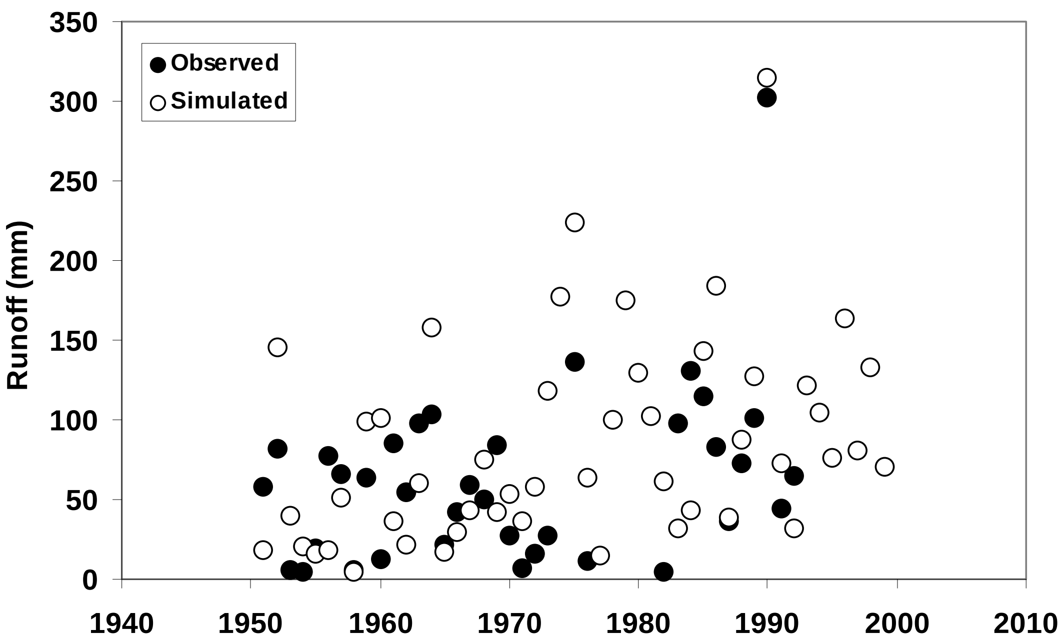
W118

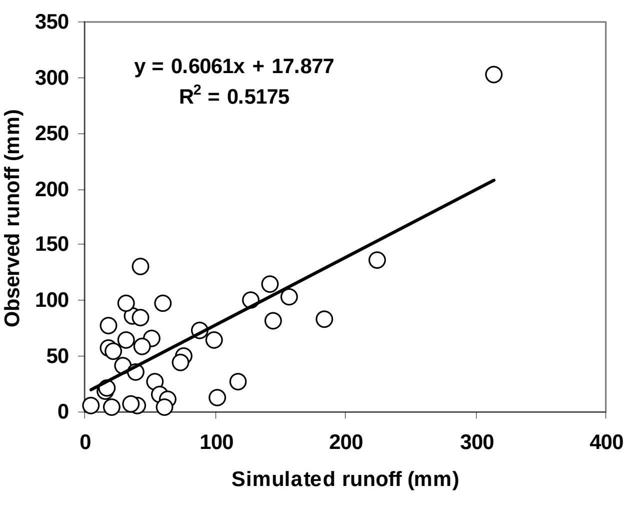
Observed and simulated corn yields at 15.5% moisture under no till (W188)



Temporal dynamics of surface runoff in W118

- **Average runoff (mm)**
  - **Observed:** **63.1±9.3 mm**
  - **Simulated:** **74.6±11.1 mm**

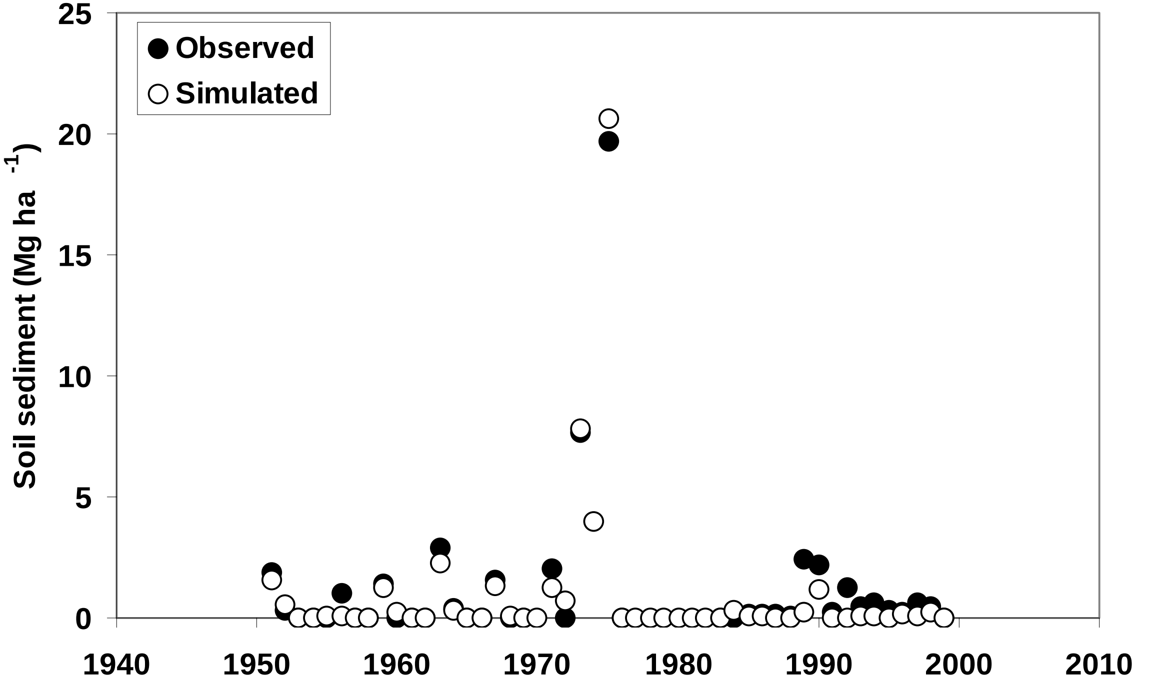




Temporal dynamics of soil sediment in W118

- **Soil sediment (Mg ha^{-1})**
  - **Observed: 1.18±0.51 Mg ha^{-1}**
  - **Simulated: 0.95±0.53 Mg ha^{-1}**

Detail of Coshocton wheel

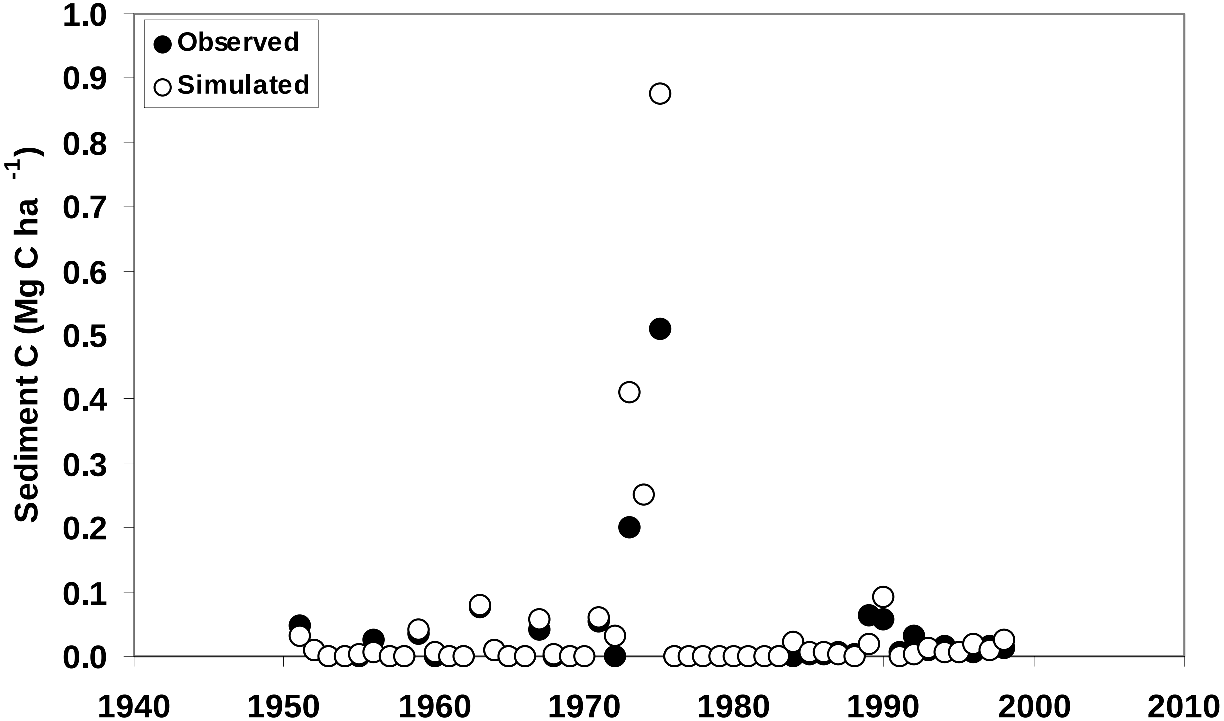


OBS = 0.949SIM + 0.241

R^2 = 0.98**

Observed and simulated sediment C collected in W118 during 1951-1999

- **Sediment C (Mg C ha^{-1} y^{-1})**
  - **Observed:** **0.031±0.014 Mg C ha^{-1} y^{-1}**
  - **Simulated:** **0.047±0.024 Mg C ha^{-1} y^{-1}**



OBS = 0.562SIM + 0.005

R^2 = 0.97**

Observed and simulated soil C after 36 years of conventional and no till

	W128 – Conv. till		W188 – No till	
Depth (cm)	Observed	Simulated	Observed	Simulated
	Mg C ha^{-1}	Mg C ha^{-1}	Mg C ha^{-1}	Mg C ha^{-1}
0 – 5	7.41 ±0.46	11.07	17.41 ±1.31	12.58
5 – 10	8.90 ±0.53	8.61	11.14 ±1.08	10.39
10 – 20	17.43 ±0.77	13.29	13.79 ±0.93	17.79
20 – 30	7.52 ±1.07	9.36	9.14 ±1.05	9.65
0 – 30	41.26	42.33	51.78	50.41

Data: Puget et al. (2005)

A comparison of annual rates of soil C erosion (Mg C ha^{-1} y^{-1}) measured or estimated in NAEW watersheds. Data for W118 are from Hao et al. (2001)

Water shed	Period	^{137}Cs	RUSLE	Soil sediment collected	EPIC This study
W118	1951 – 1999	0.041	0.149	0.026	0.047
W128	1966 – 2001	-	-	-	0.077
W188	1966 – 2001	-	-	-	0.079

Summary

- The simulation results-supported by the data- suggest that the cropping systems studied lose and redistribute over the landscape between 50 and 80 kg C ha^{-1} y^{-1} due to erosive processes
- Although the simulation results presented do not answer directly the two prevailing hypotheses, they do provide insight as to the importance of erosion-deposition processes in the C cycle at landscape, regional and global scales
- In future work, we will utilize APEX, the landscape version of EPIC, to study the role of erosion and deposition as sources or sinks of atmospheric C